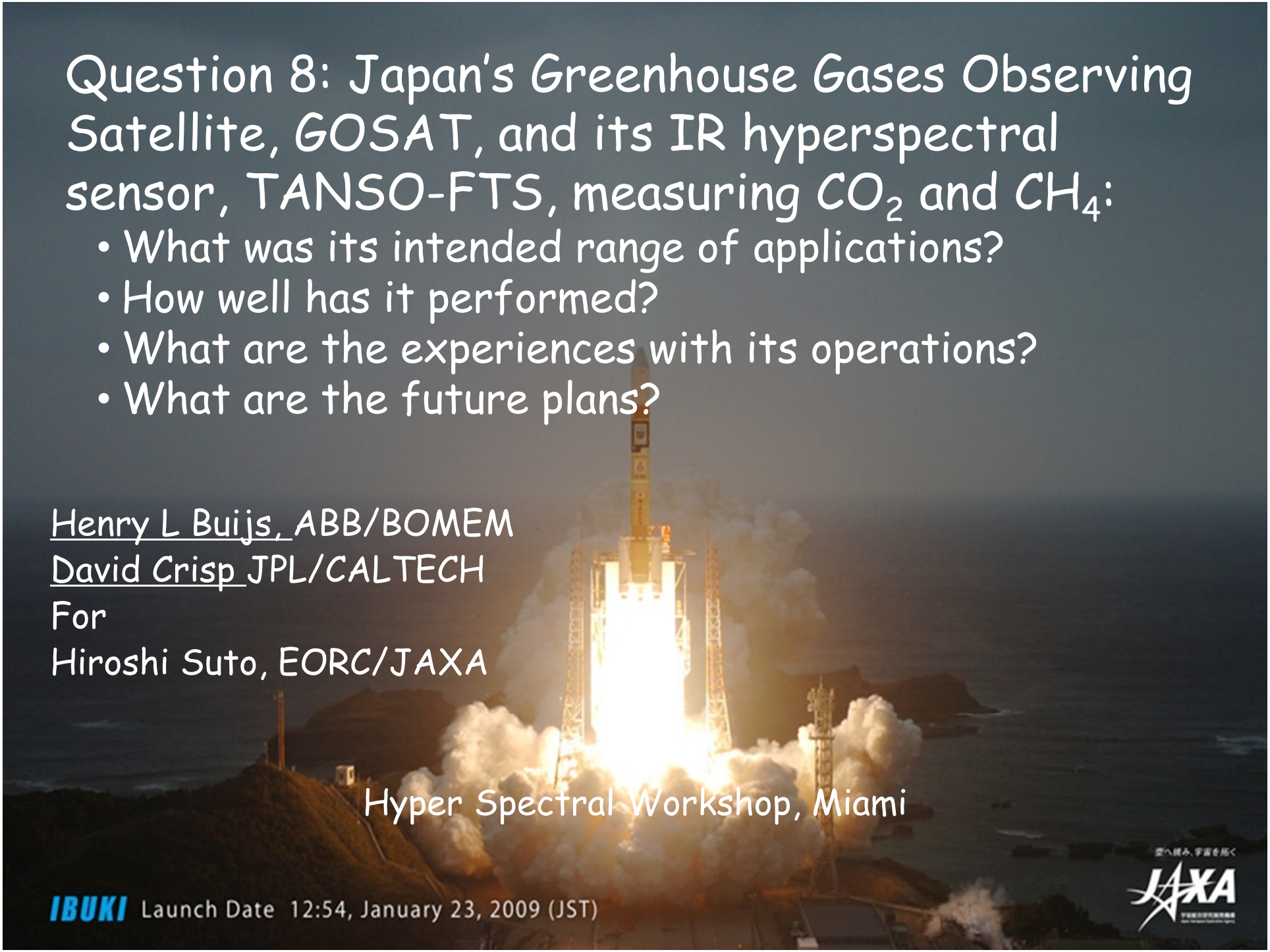
Question 8: Japan's Greenhouse Gases Observing Satellite, GOSAT, and its IR hyperspectral sensor, TANSO-FTS, measuring CO_2 and CH_4:

- What was its intended range of applications?
- How well has it performed?
- What are the experiences with its operations?
- What are the future plans?

Henry L Buijs, ABB/BOMEM
David Crisp JPL/CALTECH
For
Hiroshi Suto, EORC/JAXA

Hyper Spectral Workshop, Miami



Greenhouse gases
Observing SATellite

Great Earthquake

2011/03/11

2011/03/17

We hope we will be back from this serious situation.

Program Overview

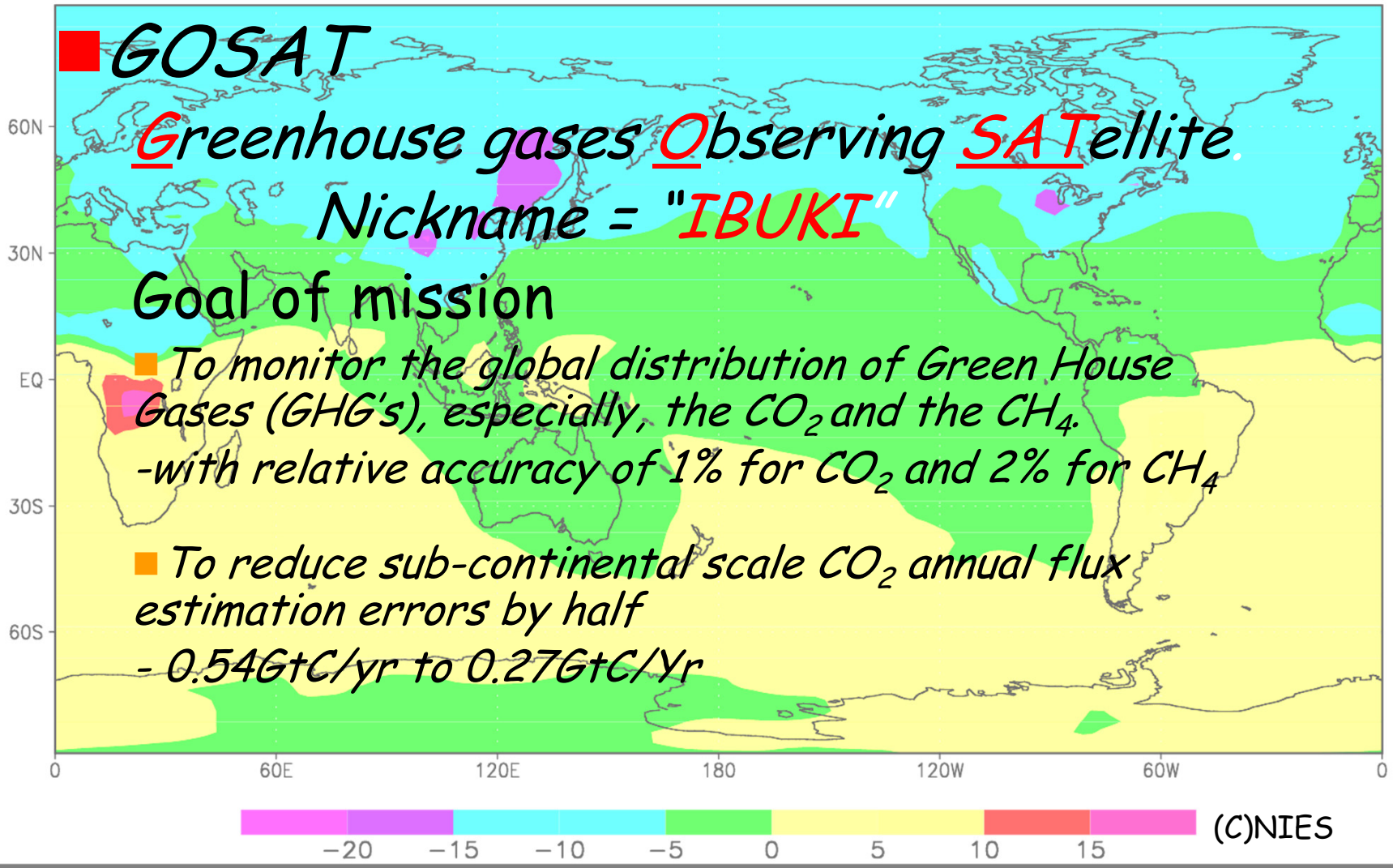
GOSAT

Greenhouse gases Observing SATellite.

Nickname = "IBUKI"

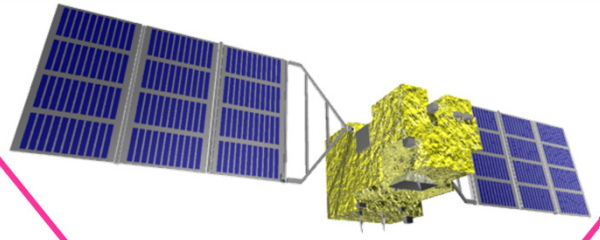
Goal of mission

- To monitor the global distribution of Green House Gases (GHG's), especially, the CO_2 and the CH_4.
  -with relative accuracy of 1% for CO_2 and 2% for CH_4
- To reduce sub-continental scale CO_2 annual flux estimation errors by half
  - 0.54GtC/yr to 0.27GtC/Yr



Organization

GOSAT is the joint project of JAXA, MOE (Ministry of Environment) and NIES (National Institute for Environmental Studies).



MOE

JAXA

NIES

- Sensor development
- Satellite development
- H-IIA launch
- Satellite operation
- Data acquisition
- Calibration

- Algorithms development
- Data use for science
- Validation

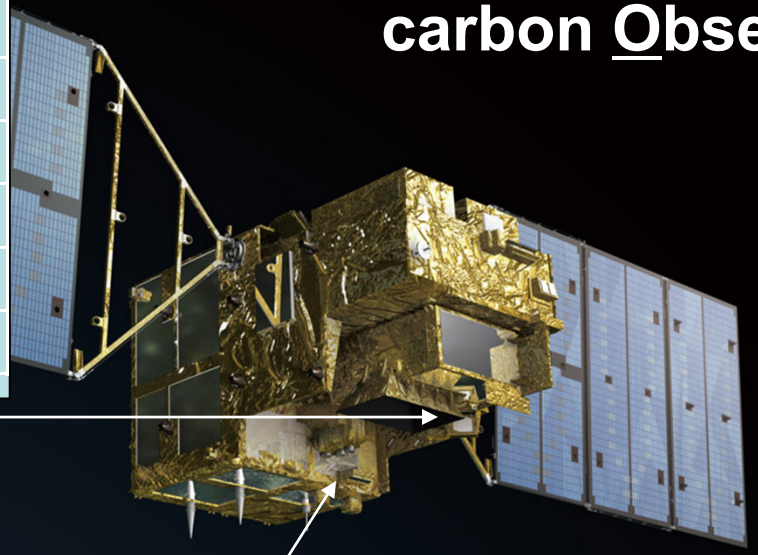
Satellite: MITSUBISHI 三菱電機

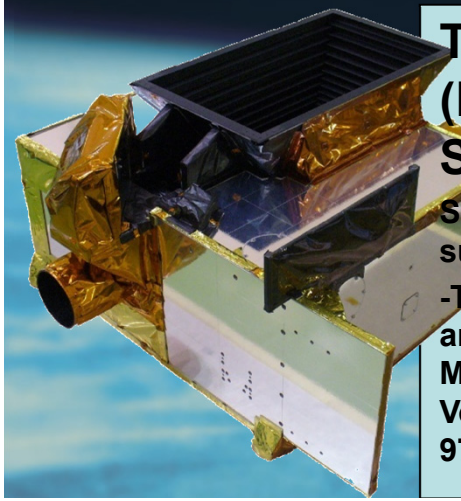
Mission Instruments: NEC/TOSHIBA NEC東芝スペースシステム株式会社, ABB

Size	Main body	3.7 m x 1.8 m x 2.0 m (Wing Span 13.7m)	
Mass	Total	1750kg	
Power	Total	3.8 KW (EOL)	
Life Time	5 years		
Orbit	sun synchronous orbit		
	Local time	13:00+/-0:15	
	Altitude	666km	
	Inclination	98deg	
	Repeat	3 days	
Launch	Vehicle	H-IIA	
	Schedule	Jan. 23 2009	

TANSO onboard GOSAT

TANSO=Thermal And Near infrared Sensor for carbon Observation





TANSO-FTS (Fourier Transform Spectrometer)

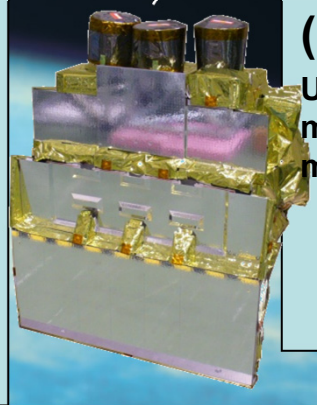
SWIR reflected on the earth's surface

-TIR radiated from the ground and the atmosphere

Mass: 15 kg

Volume: 34 cm x 22 cm x 24 cm

97.1% reliability (predicted)



TANSO-CAI

(Cloud and Aerosol Imager)

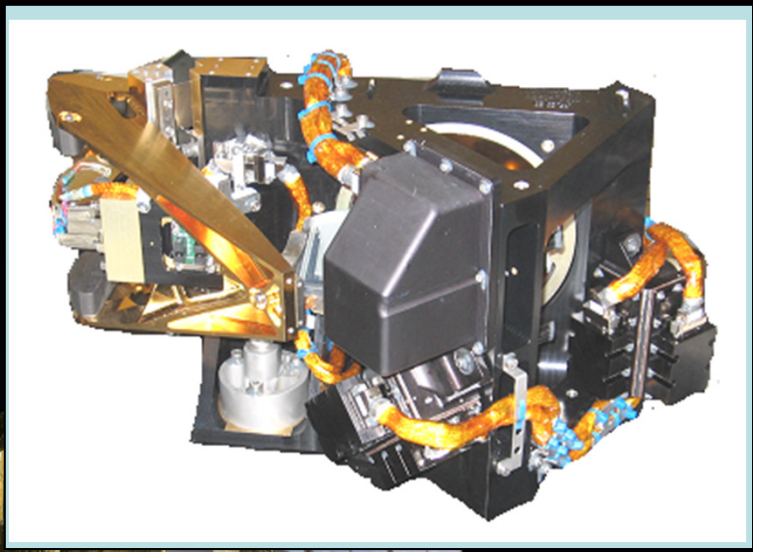
Ultraviolet (UV) (0.38 micron), visible (0.67 micron), NIR (0.87 micron), and SWIR (1.6 micron)

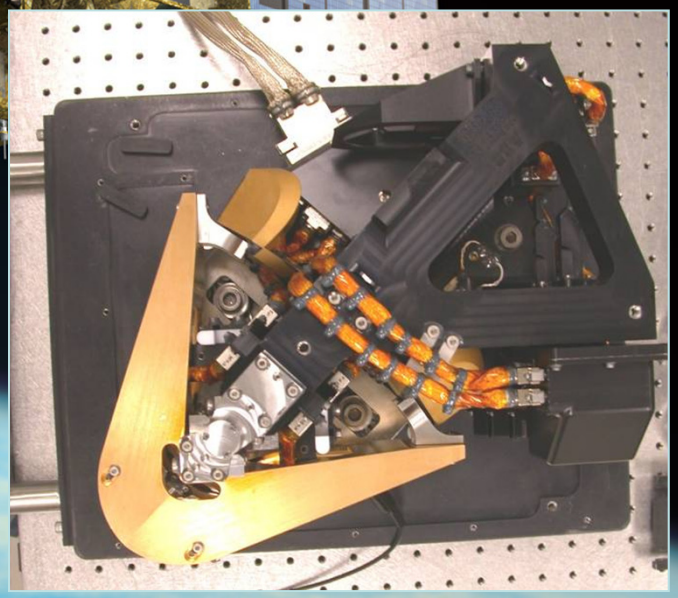
TANSO FTS characteristics

	Band1	Band2	Band3	Band4
Spectral coverage (μm)	0.758-0.775	1.56-1.72	1.92-2.08	5.56-14.3
FWHM(cm-1)	0.6	0.27	0.27	0.27
Spectral resolution(cm-1)	0.2			
Dynamic Range H	5.5e-7	5.2e-7	3.8e-7	340K
Dynamic Range M	1.8e-6	1.7e-6	1.3e-6	
Dynamic Range L (W/cm2/sr/cm-1)	5.7e-6	5.2e-6	3.8e-6	
SNR gain H / IGM 4s	300			
Wave number (cm-1)	13050cm-1	6200cm-1	5000cm-1	700cm-1
input radiance (W/cm2/sr/ cm-1)	5.5e-7	5.2e-7	3.8e-7	280K
IFOV at Nadir	15.8mrad / 10.5km			

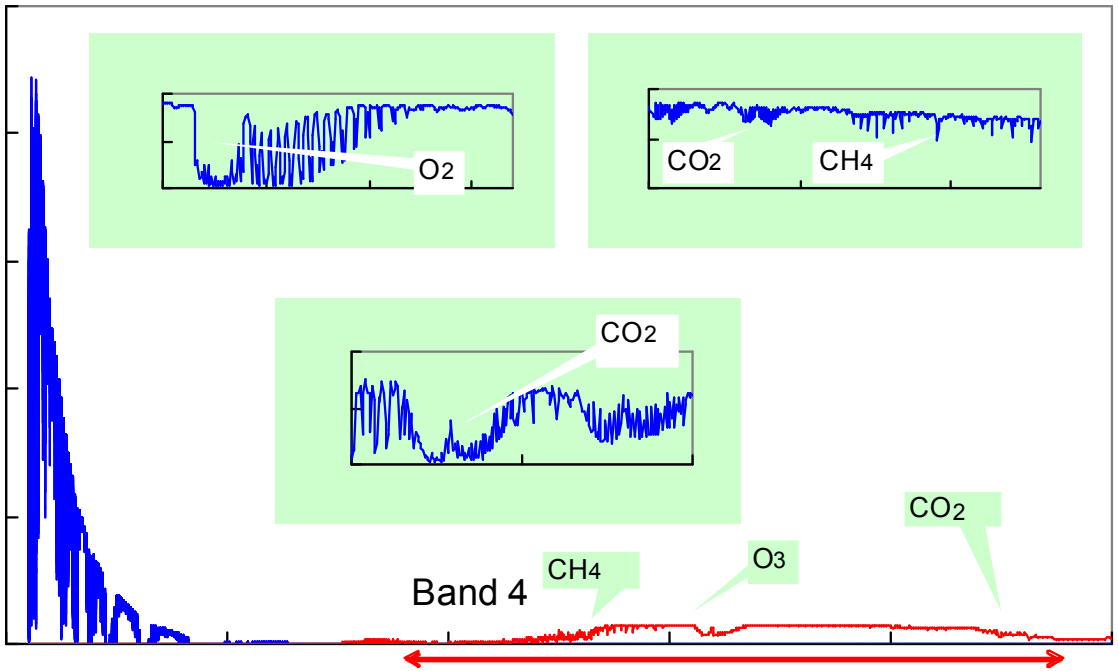
TANSO FTS characteristics

- Michelson-like
- Cube corners on “V”-shape scan arm
- Double-sided sweep, 2.5 cm MPD (0.2 cm^{-1} resolution)
- Self-compensated beamsplitter (proprietary)
- Laser metrology based on 1310 nm laser diodes
  - Fringe count for actuator servo-control + IR sampling
  - Direction determination
- Aluminum structure
  - Flex mounts to interface with carbon fiber optical bench





Spectral Coverage and Absorption Lines



- 3 narrow bands
  - 0.76micron
  - 1.6micron and
  - 2micron
- A wide band
  - 5.5 – 14.3 micron
- With 0.2cm^{-1} spectral resolution

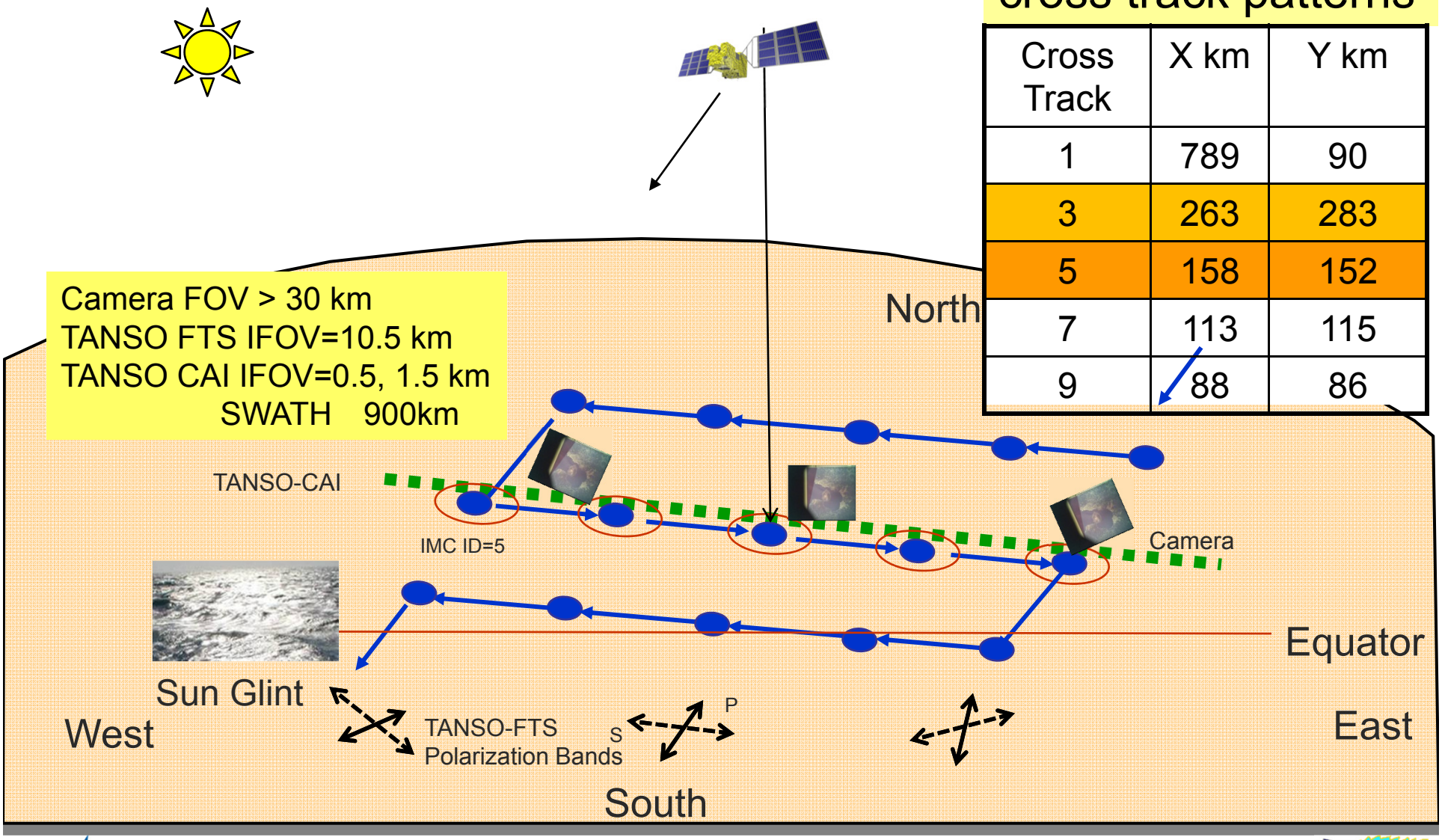
- Column density of CO_2 is mainly retrieved by using the absorption lines between 1.6micron (Band 2) region.
  - The intensities of these lines are less temperature dependent and not interfered by other molecules.
- O_2 A band absorption at 0.76 micron are used to estimate the effective optical path length.

Pointing and Footprints

cross track patterns

Cross Track	X km	Y km
1	789	90
3	263	283
5	158	152
7	113	115
9	88	86

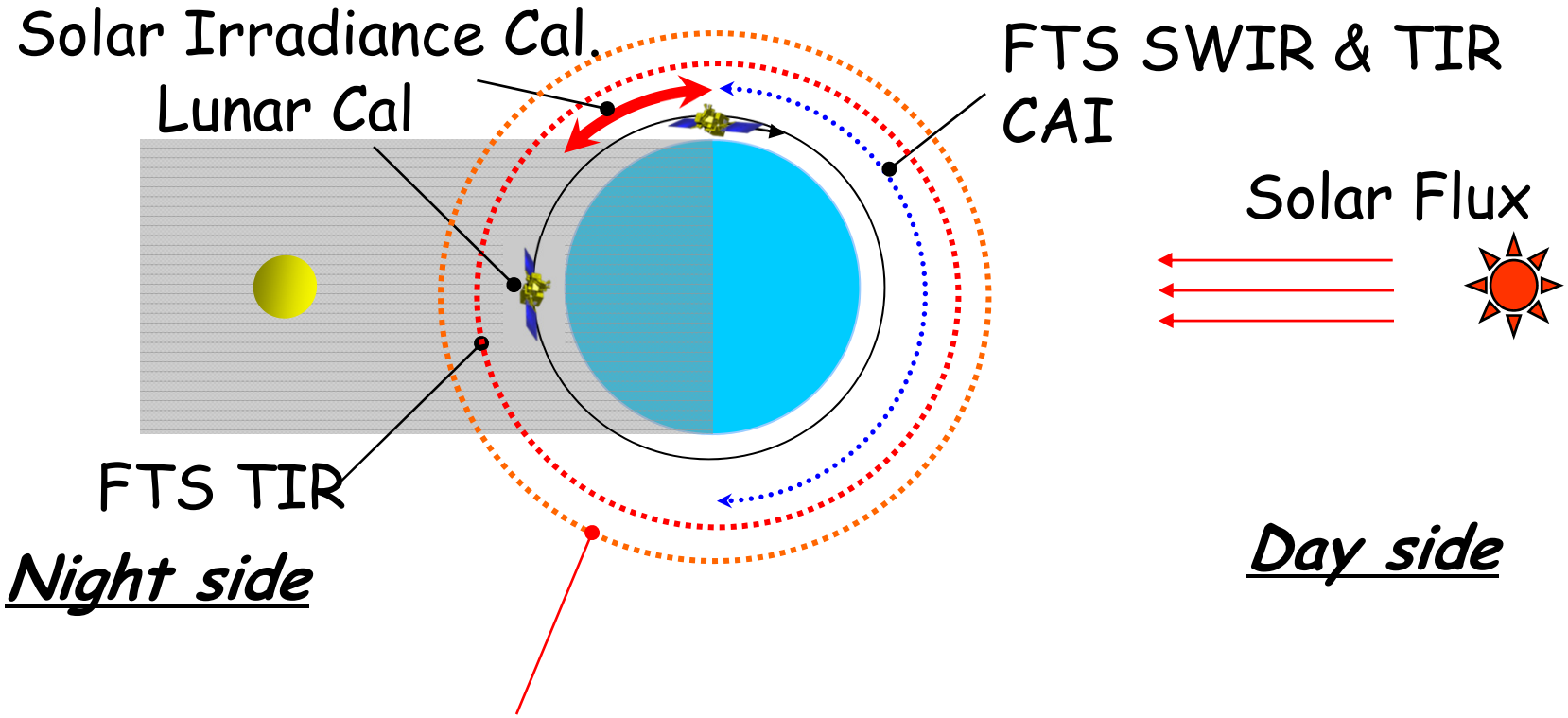
Camera FOV > 30 km
TANSO FTS IFOV=10.5 km
TANSO CAI IFOV=0.5, 1.5 km
SWATH 900km



Scanning modes

- Observation per IFOV
  - Selectable, 1.1 s., 2 s. and 4s.
  - Scan times are synchronized to orbit time
    - To permit precise revisit location every 3 days
- Selectable number of cross track IFOVs
- Also specific target selection
  - Including sun glint tracking over water

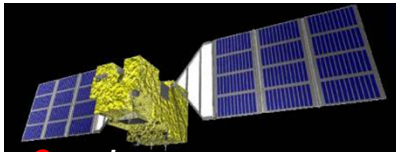
Operation



Special observation mode: FTS-Diagnostic Mode,
Viewing the diffused LD light during a few orbit.

How well has it performed?

- GOSAT was successfully launched from Tanegashima Space Center on a H-IIA Launch vehicle on 23 January 2009
- "First Light" images and spectra taken on 9 February 2009
- Initial Cal/Val completed an routine operations started in July 2009
  - First global maps collected in April 2009
- First Level 2 X_{CO2} and X_{CH4} products released in February 2010
- 3 Research Announcements released
  - 106 proposals have been selected
  - Next RA Meeting: 19-20 May, Edinburgh, U.K.



Greenhouse gases
Observing SATellite

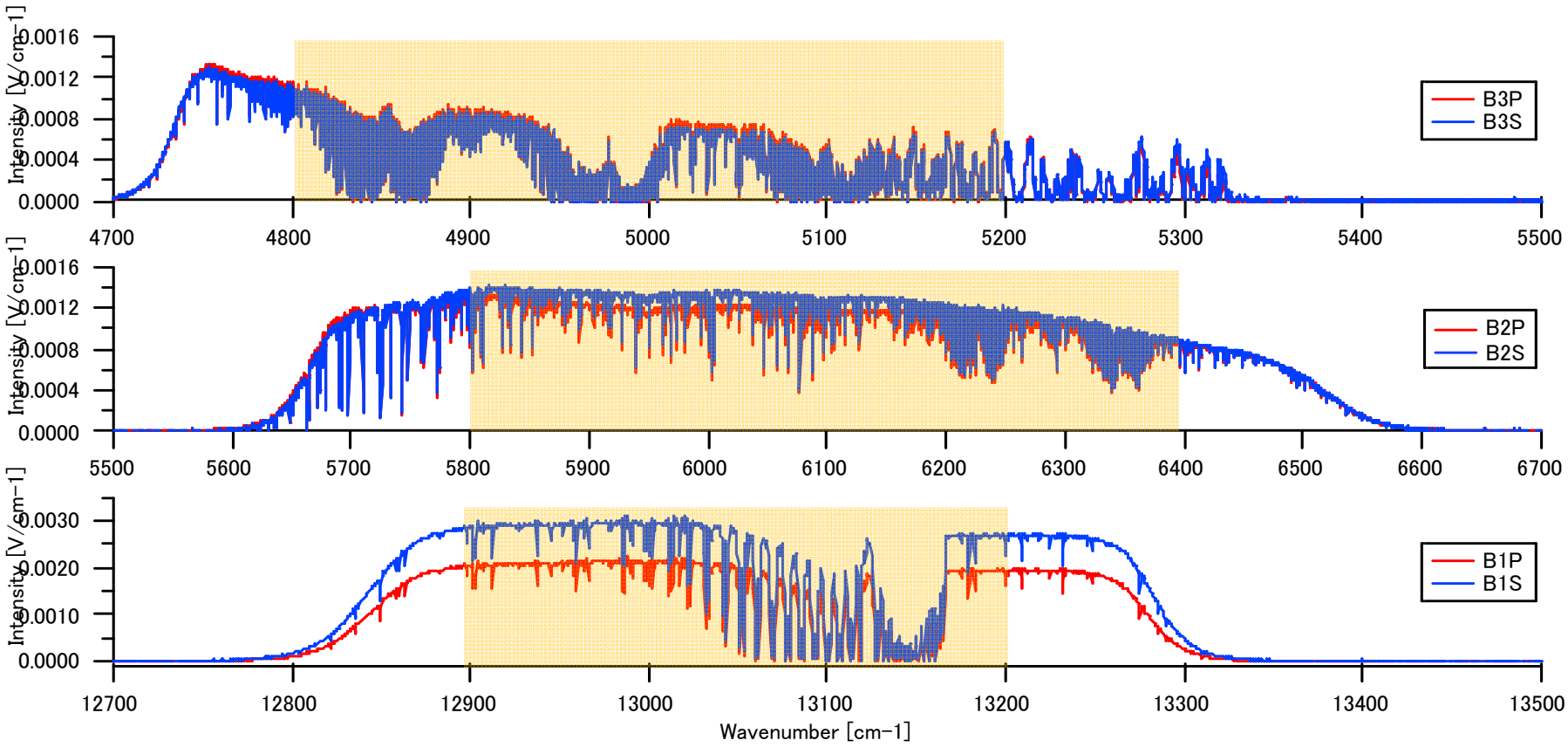
How well has TANSO-FTS performed?

- FTS exceeds signal to noise ratio expectations in all bands
- Spectral quality is very good
  - Very accurate ILS
  - Very stable repeatable spectra
- Requires correction algorithm for vibration resonance effect
- 4s. Scan time gives best results
  - Has precise compensation for vibration influence
- Minor non-linearity effect due to ADC in band 1
  - Correction algorithm being developed.
- Calibration issues with Thermal IR band 4
- Goal of mission not yet achieved
  - Retrieval issues still being worked

JAXA
宇宙航空研究開発機構
Japan Aerospace Exploration Agency

GOSAT

First FTS Data



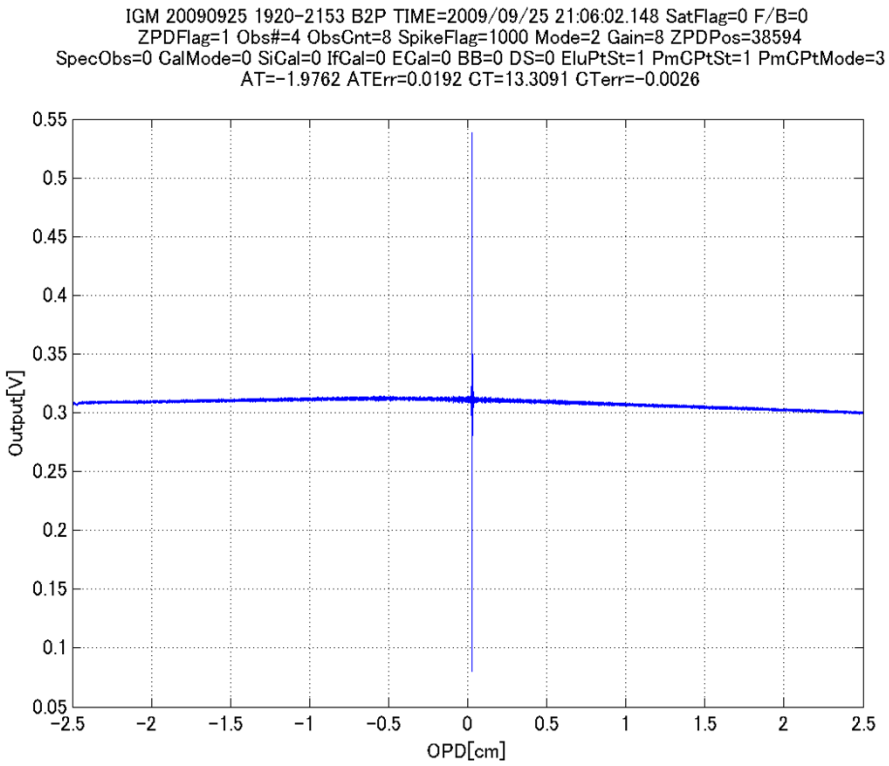
Successfully detected from space at Visible (760nm) and SWIR(1.6, 2.0um) with High resolution.

TANSO-FTS Anomalies

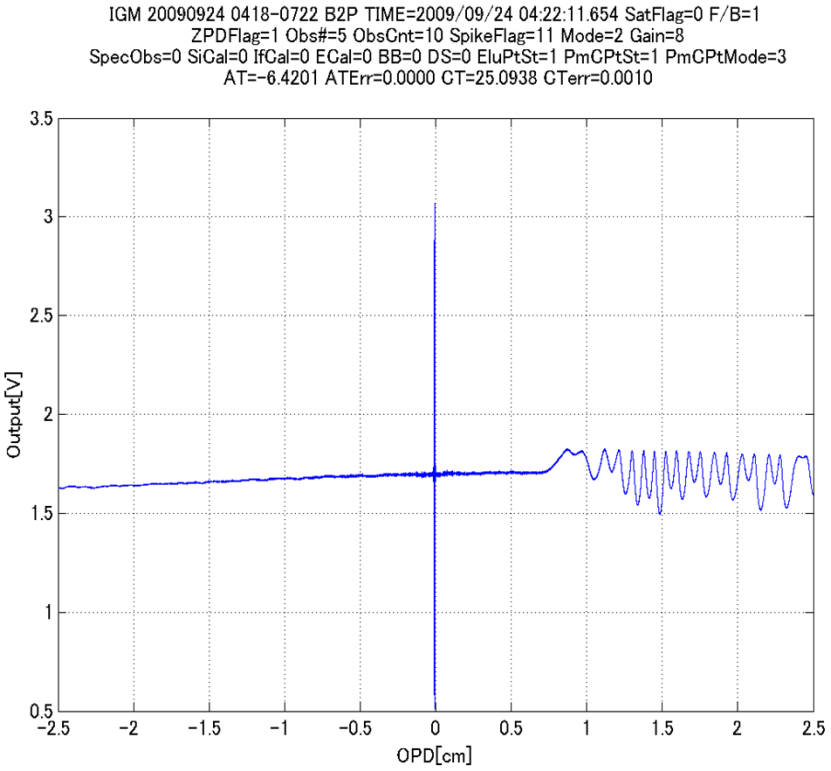
A few anomalies have been identified and are under investigation

- 10-20 % of recorded interferograms have anomalous fluctuations.
  - Can be distinguished by checking level 1 data quality flag.
- TANSO-FTS Zero Path Difference (ZPD) shift
  - Problem mitigated by resetting FTS once every 2 weeks
- Sampling laser signal level decreases very slowly due to misalignment
  - No impact on performance (small wavelength shift).
- TANSO-FTS onboard camera data detected a few km pointing offset .
- Radiometric response degradation has been observed
  - The largest impacts seen at the shortest wavelengths
- TANSO-FTS Band 1 Nonlinearity – Currently under investigation

Pointing AT-Instability



Typical “good” IGM

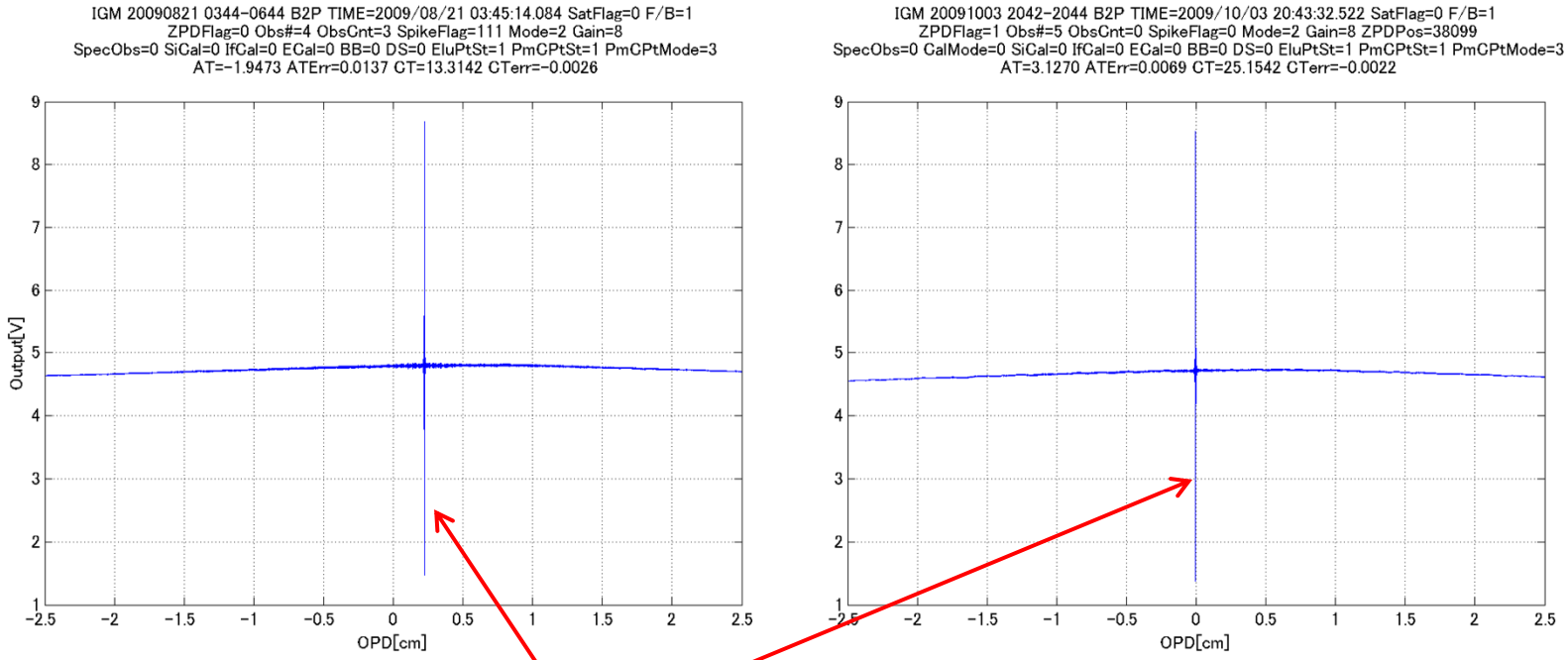


Typical “anomaly” IGM

Before v.050, we can not assigned these type of IGM by listed flags.

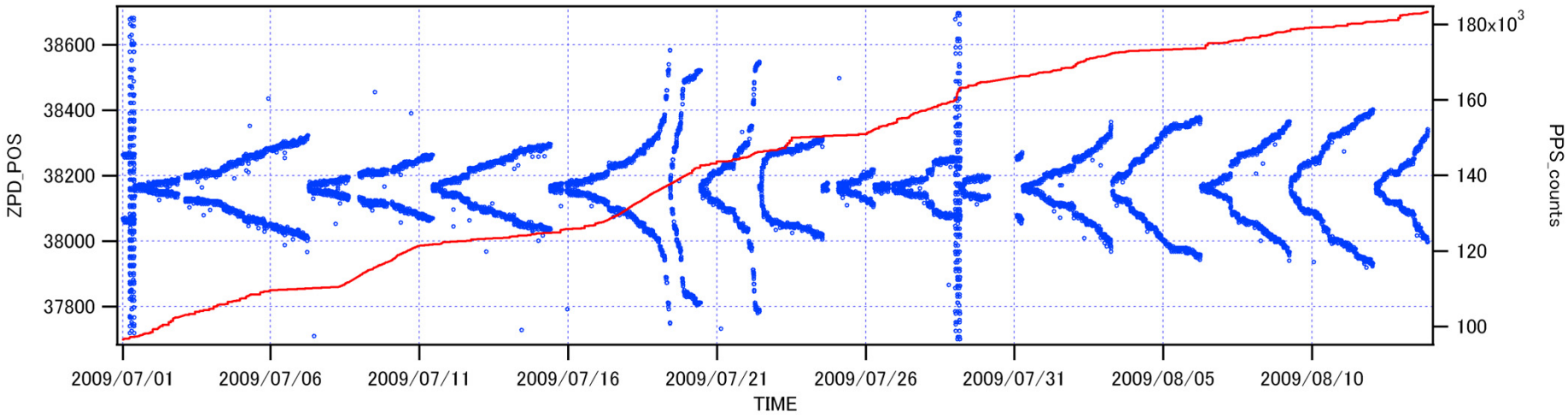
ZPD shift (1/2)

From 04 May. UT6:00, the change of Zero Path Difference Position (ZPD) was observed.



The changing speed and number are random, no regularity

ZPD shift (2/2)

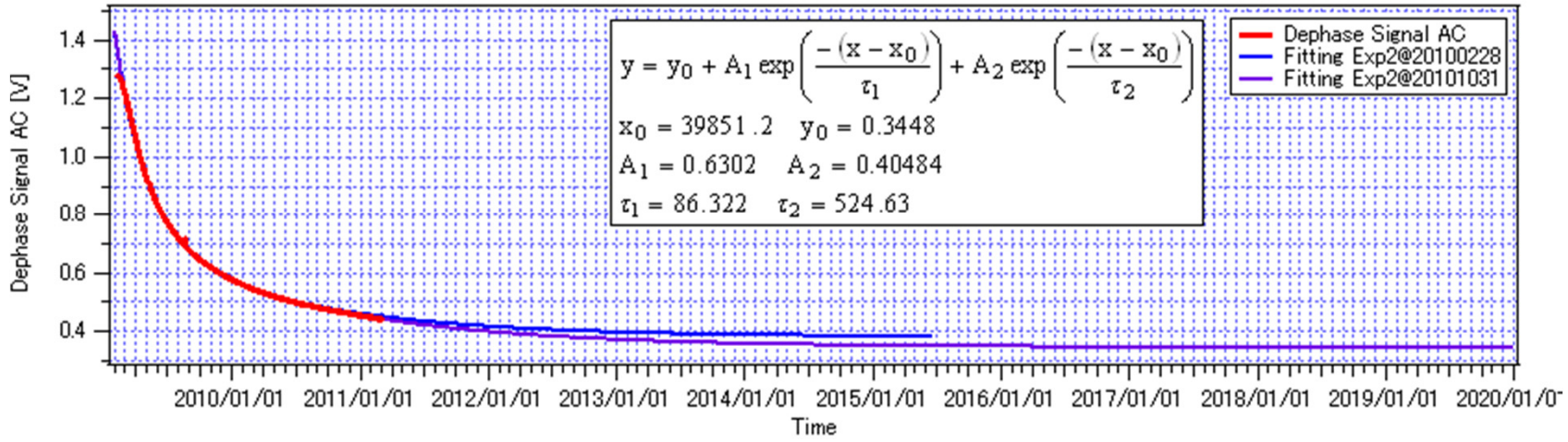


- To avoid the large shifts, ZPD position is corrected if necessary.
(Criteria is +/- 40 shifts)

Degradation of sampling signal

All level of sampling signal (phase/dephase, AC/DC: to determine the mirror position) are decreasing on-orbit.

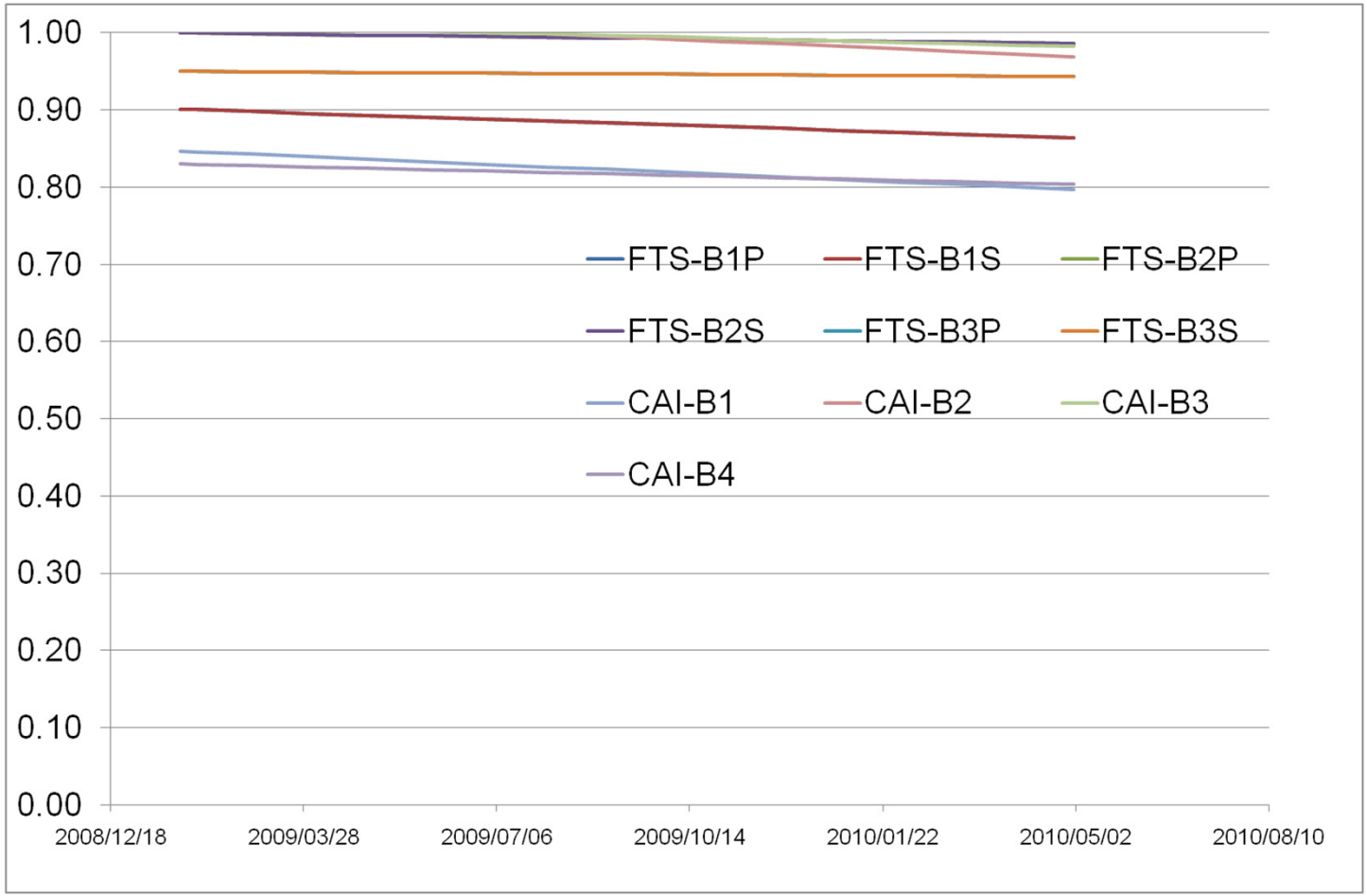
>> Fitting curve suggests us that the degradation speed tend to be slow and stop in near future.



The trend of Dephase AC signal

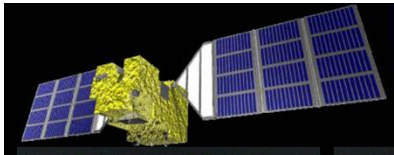
(lowest signal in critical signal, Fringe/Dephase AC)

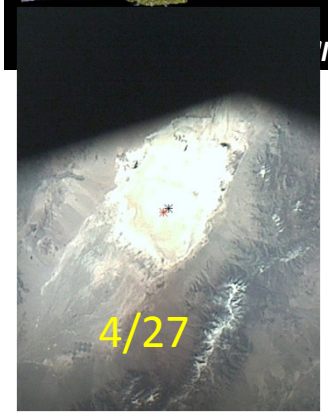
Radiometric Degradation

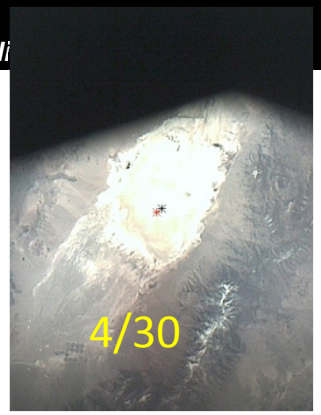


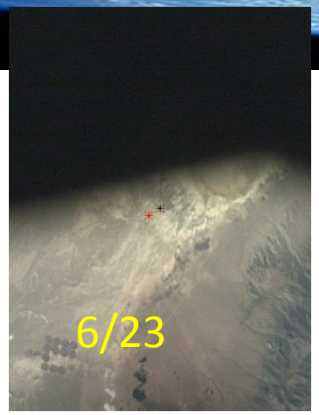
Band1 degradation might be mainly caused by just after launch or pre-launch calibration error.

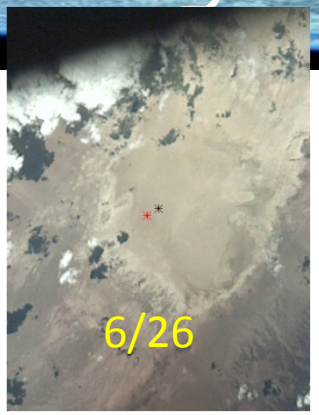
Pointing anomaly

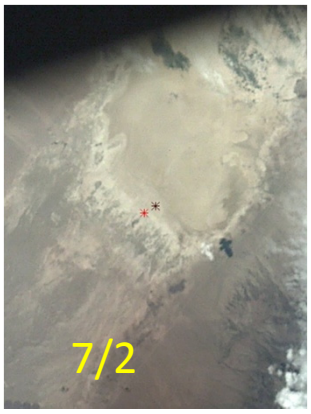


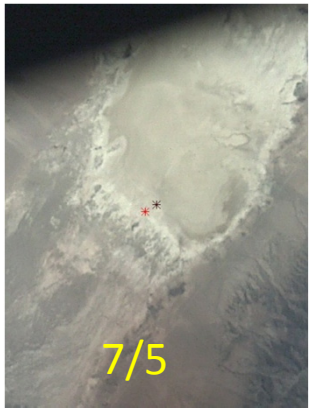


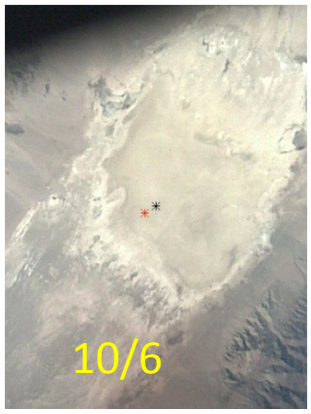


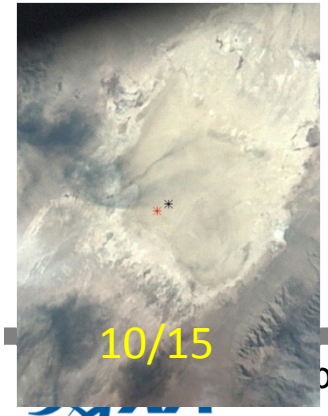


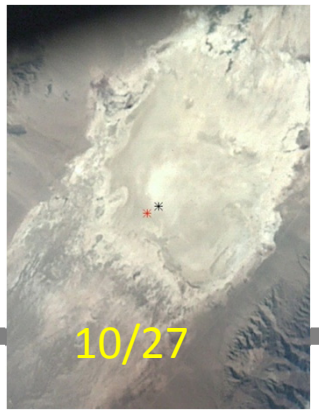


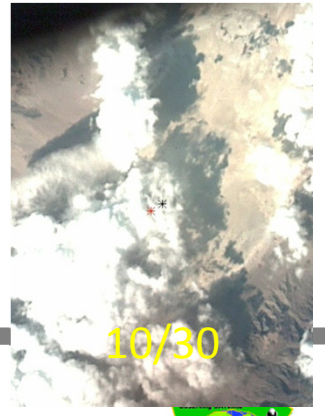






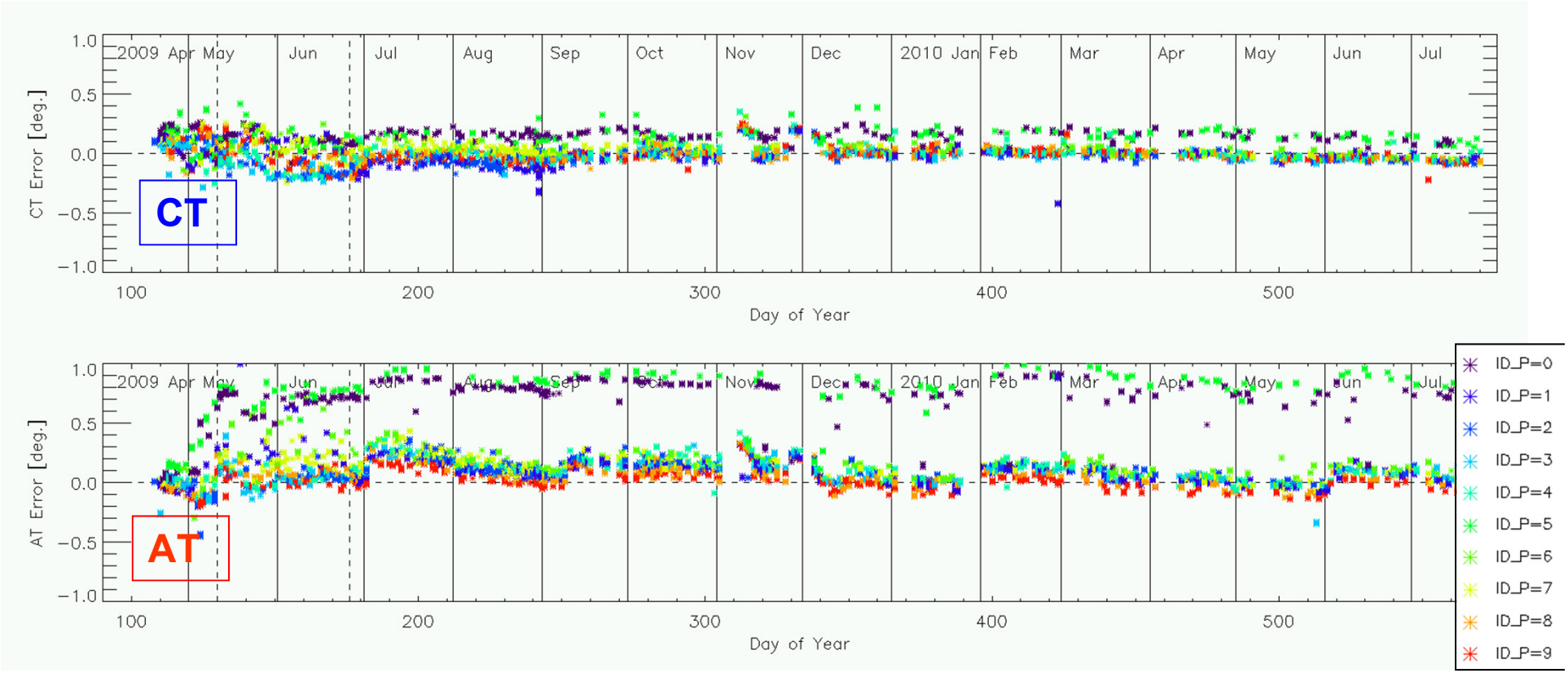






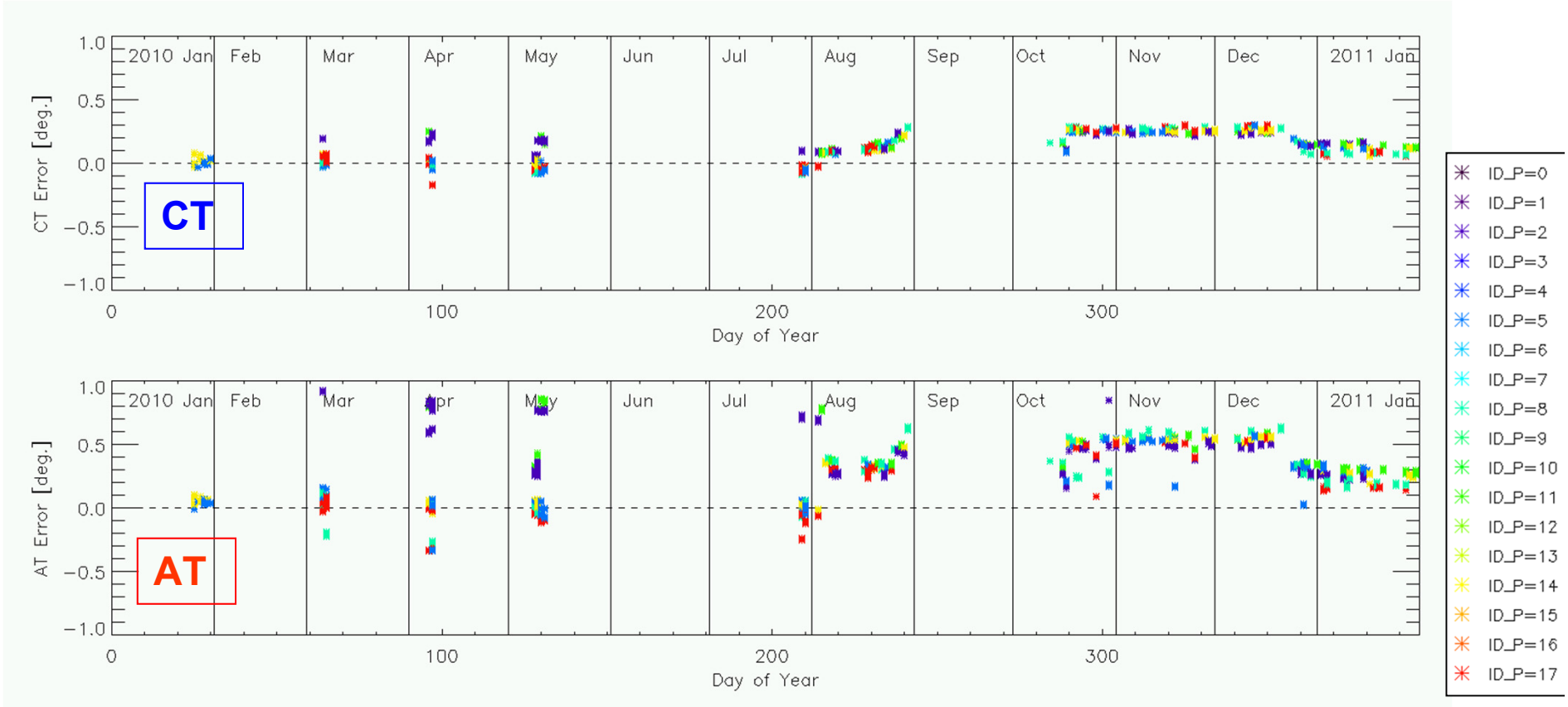
Pointing anomaly (5 point mode)

- Pointing target position error was analyzed applying onboard Camera image.
- Pointing has systematic offset values that are changing with time.
  - Along-track (AT) values show greater offsets than Cross-track (CT)

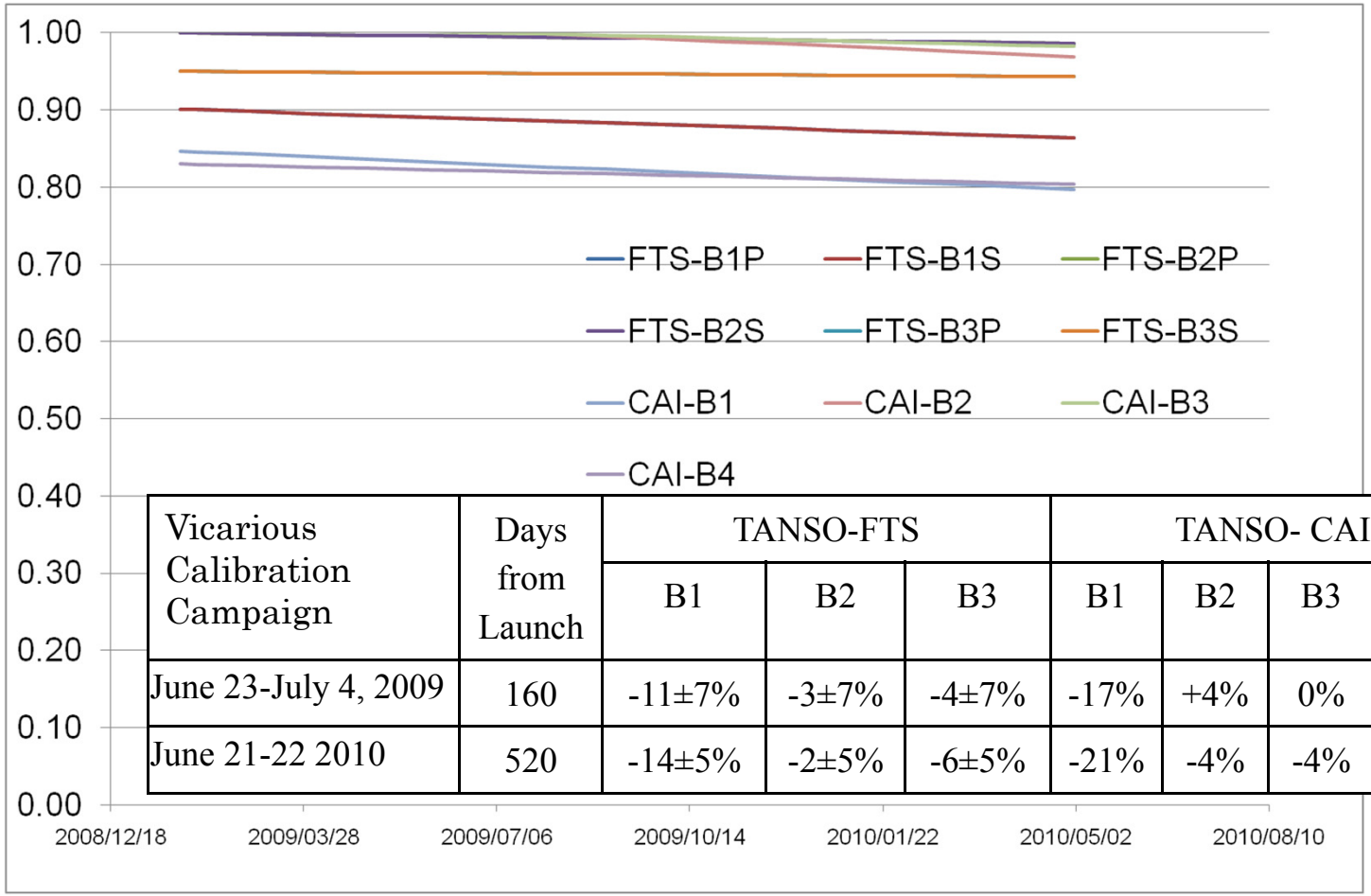


Pointing anomaly (3 point mode)

- Pointing target position error was analyzed using onboard Camera images.
- Pointing still has systematic offsets that change with time, but both amplitude of offset and variability are substantially smaller in 3-point mode



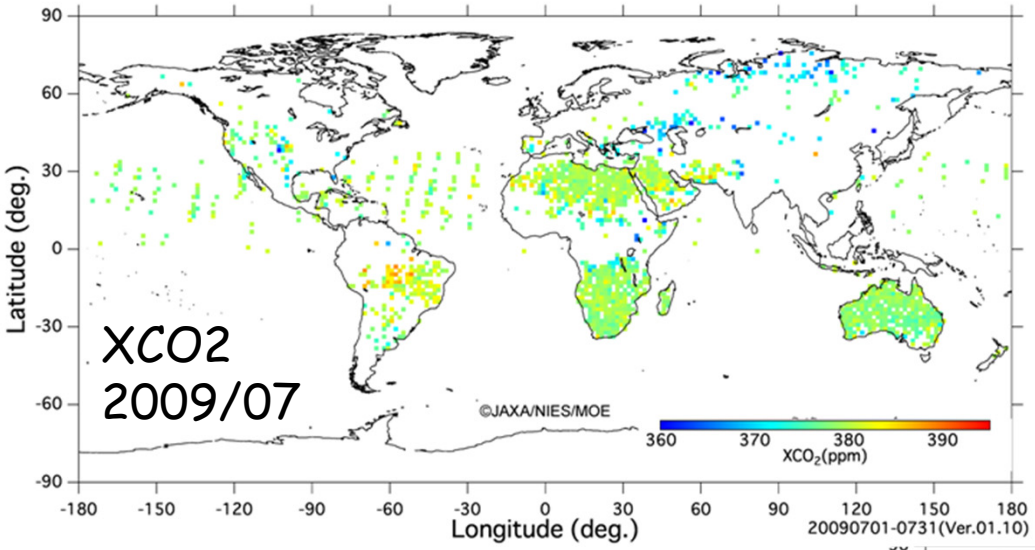
Radiometric Degradation



Vicarious Calibration Campaign	Days from Launch	TANSO-FTS			TANSO- CAI			
		B1	B2	B3	B1	B2	B3	B4
June 23-July 4, 2009	160	-11±7%	-3±7%	-4±7%	-17%	+4%	0%	-18%
June 21-22 2010	520	-14±5%	-2±5%	-6±5%	-21%	-4%	-4%	-20%

Band1 FTS and CAI degradation may have occurred just after launch or may be due to a pre-launch calibration error.

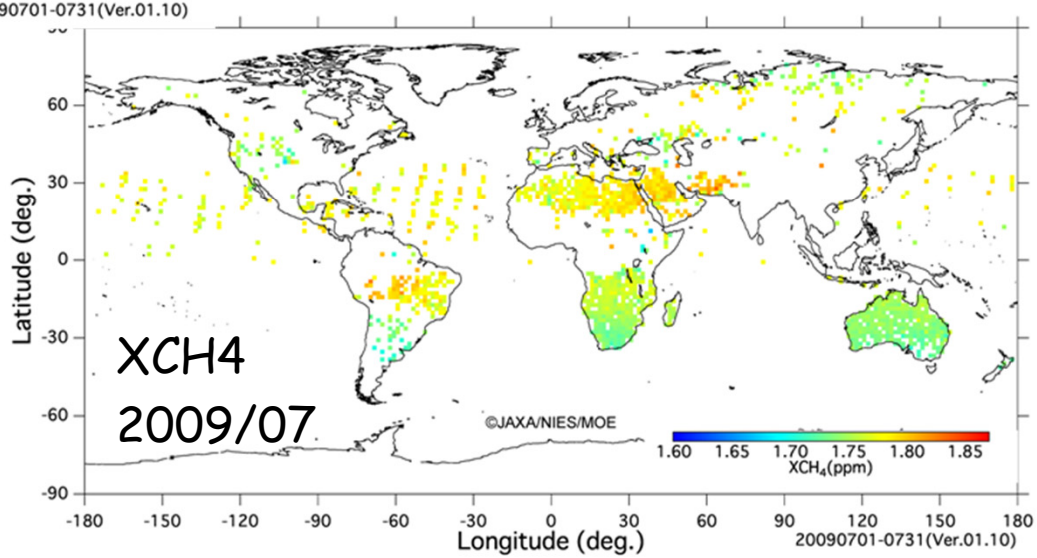
Global Map for GHG



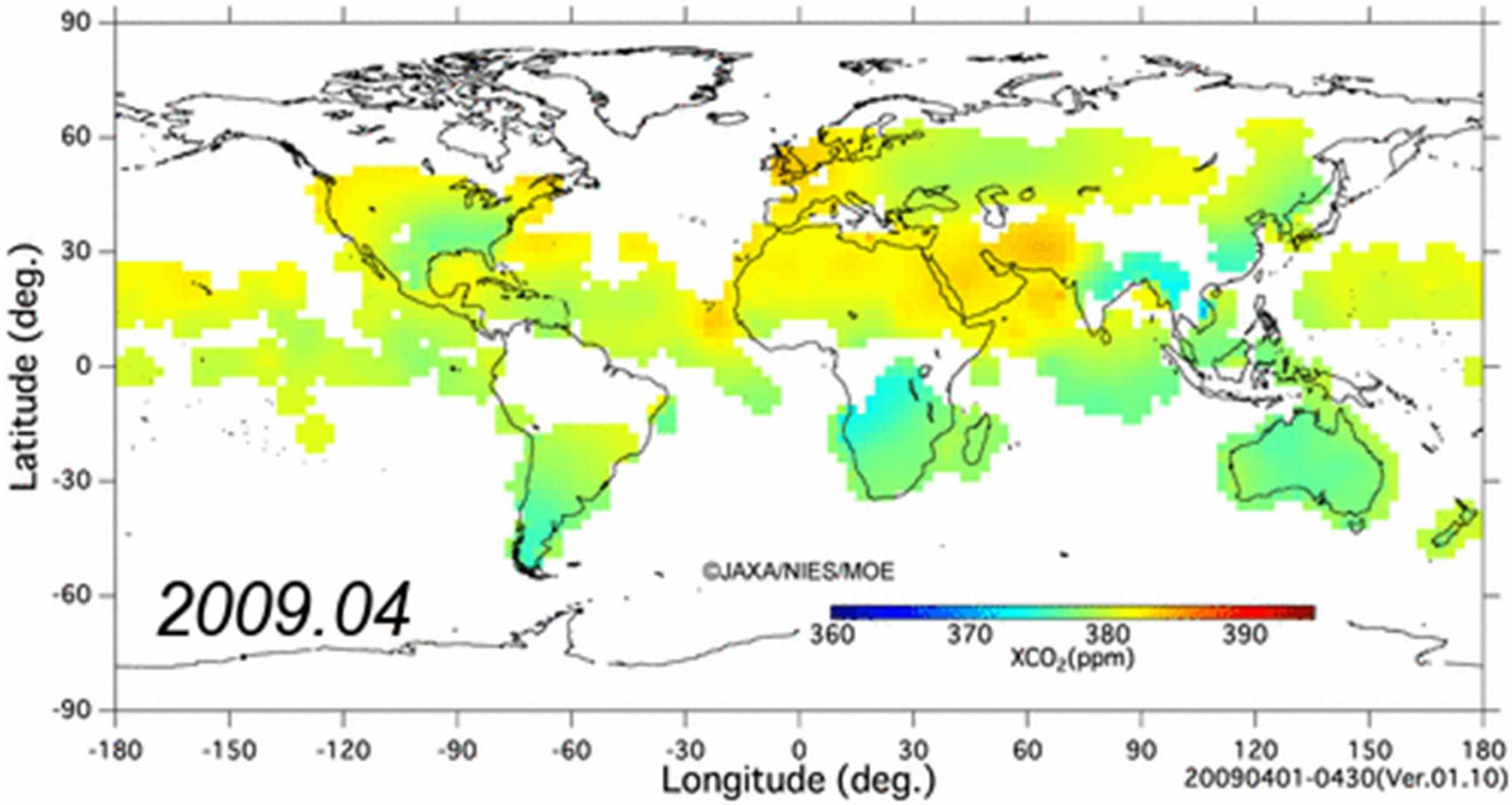
NIES is using the GOSAT measurements to retrieve X_{CO2} and X_{CH4}

These data have biases, and are affected by dust aerosols, however, the overall data distribution trend is reasonable.

The retrieved results will be revised as the instrument calibration and retrieval algorithms improve.



Global Map for GHG



Level 3 data provided by NIES

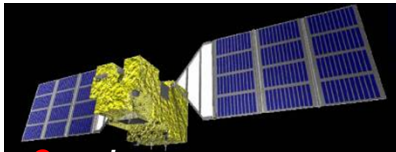
Biases for GOSAT Data

Biases of CO_2 and CH_4 (+8.9ppm and +0.02ppm)

Surface pressure bias might be main cause.

- Band1 non-linearity (mainly caused by 16bit ADC character)
- Band1 ILSF
- aerosol handling

NIES, ACOS and JAXA will try to find a solution.



Greenhouse gases
Observing SATellite

Summary of GOSAT Performance

- GOSAT has been successfully collecting global measurements needed to retrieve X_{CO2} and X_{CH4} since April 2009
- While a few instrument anomalies have been identified, their impacts on the GOSAT data products are being mitigated through
  - An on-orbit radiometric calibration program, incorporating
    - Direct observations of the lunar disk
    - Observations of reflected sunlight from primary and backup targets
  - An on-orbit geometric calibration program using internal cameras
  - Annual vicarious calibration campaigns in Railroad Valley, Nevada
  - Laboratory measurements using the GOSAT Engineering Model
- GOSAT Level 1B products can be obtained from:

  http://data.gosat.nies.go.jp/